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**AIR JET ATOMIZATION AND BURNING
OF OIL SLICKS**

by

S.L. ROSS ENVIRONMENTAL RESEARCH LIMITED

for

**UNITED STATES DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE**

and

**ENVIRONMENT CANADA
ENVIRONMENTAL EMERGENCIES TECHNOLOGY DIVISION**

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BACKGROUND

The original work statement for the project included the small scale testing of both air jet and ultrasonic oil atomizing transducers to be provided by the scientific authority. Unfortunately, initial testing of the ultrasonic transducers developed for this application revealed that they were not able to handle the power input required for effective oil atomization from the water surface. At this point the project was modified in consultation with the scientific authority to address only the use of air jet atomization. A small scale laboratory evaluation was undertaken to assess the merit of atomization of oil slicks by this method. Following this lab scale work the air jets were tested in combination with a full scale burner provided by the scientific authority. The results of these lab and field test programs are discussed in the following sections.

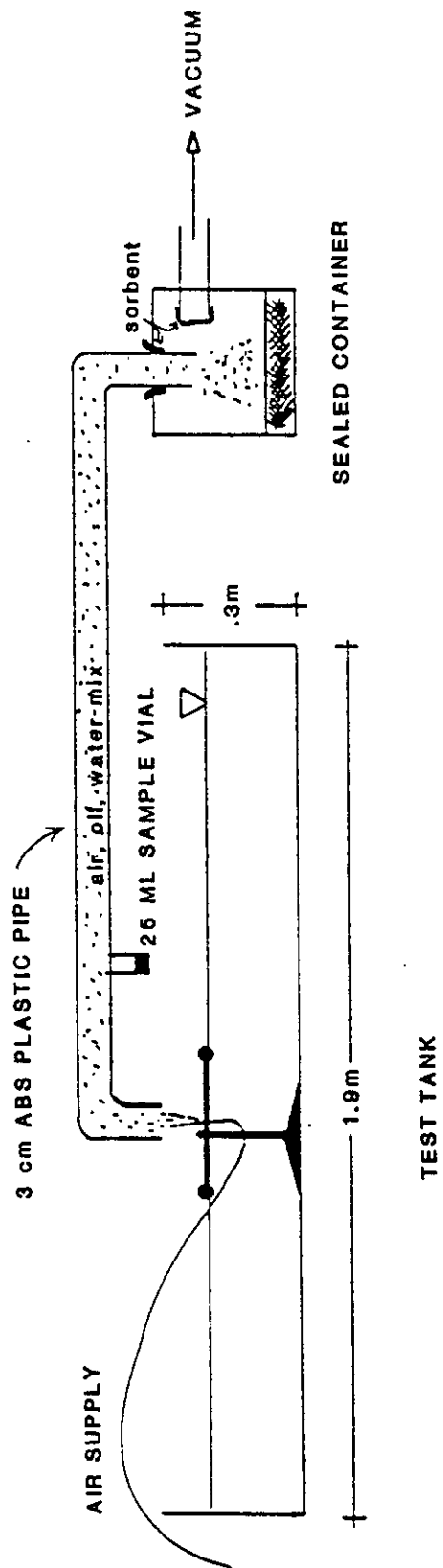
SMALL SCALE TESTING OF AIR JET ATOMIZATION

Figure 1 illustrates the experimental set up used to evaluate the air jets. The tank used was 1.9 m in diameter and 0.3 m deep. Oil was contained on the water surface above the air jets with a floating containment ring 0.5 m in diameter. The air jet nozzles were held in place using a simple stand placed in the tank which allowed for vertical adjustment of the nozzle position. Air was provided to the nozzle via a (560 watt 3/4 horsepower) compressor, pressure tank and pressure regulator. The most difficult aspect of this phase of the study was the collection of the product generated by the air jets. After several failed attempts the arrangement seen in Figure 1 was finally used in the testing. The primary problem encountered in collecting the liquid product was in venting the high volume of air being pushed by the atomizing nozzles without losing the atomized oil entrained in the air.

Forty-one tests were conducted using various combinations of 4 nozzles (2 blunt, 2 conical), 3 nozzle depths, three oil depths and 3 air pressures. The results seen in Table 1 indicate the following basic trends.

- i) For nozzle depths greater than 2 cm below the water surface atomization of oil was impractical since the water content of the product was frequently greater than 90%. Little "atomization" occurred; instead, a spout of water was formed regardless of nozzle type or diameter.
- ii) When the nozzles were positioned 2 cm below the water-oil interface atomization occurred but water contents were again generally in the 80-100% range for the collected product. Oil recovery rates were significant in this position but it would appear that for an effective burn to occur the nozzles would have to be operating at the oil water interface to eliminate excessive water uptake.
- iii) When the nozzles were operated at the oil-water interface water uptake was about 50% for 0.5 mm slicks dropping to 10% or less for the 2 and 4 mm slicks. Changing the nozzle type (conical vs. blunt) appeared to have little effect on oil recovery rate. Larger diameter nozzles increased the recovery rate as did a drop in pressure from 275 to 200 to 140 kPa. This is likely due to a lower velocity air jet and its ability to "pull" oil to the main air stream rather than

FIGURE 1 Small Scale Test Apparatus



**TABLE 1:
AIR ATOMIZATION LAB SCALE EXPERIMENTAL RESULTS**

Nozzle Data	Test #	Pressure (kPa)	Depth of Nozzle (mm)	Depth of Oil (mm)	Height Spray (cm)	Water in Product (%)	Total (g/s)
#4C*	1	275	20.5	0.5	>195	91.67	9.743
ID=3mm	2	275	22.0	2.0	>195	89.58	11.763
OD=5mm	3	275	24.0	4.0	>195	40.91	64.671
#4C	5	275	0.5	0.5	>195	45.83	3.519
ID=3mm	6	275	2.0	2.0	>195	7.14	18.350
OD=5mm	7	275	4.0	4.0	>195	2.40	6.318
#1B+	8	275	0.5	0.5	>195	50.00	5.072
ID=2mm	9	275	2.0	2.0	>195	43.75	4.191
OD=8-12mm	10	275	4.0	4.0	>195	6.52	6.472
#1B	11	275	80.5	0.5	35	96.00	
ID=2mm	12	275	82.0	2.0			
OD=8-12mm	13	275	84.0	4.0			
#1B	14	275	40.5	0.5	80		
ID=2mm	15	275	42.0	2.0			
OD=8-12mm	16	275	44.0	4.0			
#1B	17	275	20.5	0.5			
ID=2mm	18	275	22.0	2.0			
OD=8-12mm	19	275	24.0	4.0			
#1B	20	275	10.5	0.5	>140	95.83	2.582
ID=2mm	21	275	12.0	2.0	>165	47.83	28.966
OD=8-12mm	22	275	14.0	4.0	>165	40.00	39.344
#3C	23	275	0.5	0.5	>195	65.38	4.053
ID=3mm	24	275	2.0	2.0	>195	30.43	25.805
OD=7mm	25	275	4.0	4.0	>195	6.25	41.747
#3C	26	275	0.0	0.5	>195		
ID=3mm	27	275	0.0	2.0	>195		
OD=7mm	28	275	0.0	4.0	>195	0.00	1.000
#3C	29A	275	20.5	0.5	>195	96.00	6.058
ID=3mm	29B	275	22.0	2.0	>195	96.00	4.785
OD=7mm	29C	275	24.0	4.0	>195	84.00	21.020
#2B	30	275	0.5	0.5	>190	52.17	3.956
ID=6mm	31	200	0.5	0.5	>165	55.00	4.941
OD=9mm	32	140	0.5	0.5	>165	27.78	12.418
#2B	33	275	2.0	2.0	>195	4.35	19.941
ID=6mm	34	200	2.0	2.0	>180	7.89	12.725
OD=9mm	35	140	2.0	2.0	>165	3.75	14.347
#2B	36	275	4.0	4.0	>195	27.78	11.038
ID=6mm	37	200	4.0	4.0	>195	5.79	16.794
OD=9mm	38	140	4.0	4.0	>195	1.09	24.683
#2B	39	275	20.5	0.5	>195	100.00	0.000
ID=6mm	40	275	22.0	2.0	>165	80.00	20.793
OD=9mm	41	275	24.0	4.0	>190	65.38	28.058

* conical nozzle
+ blunt nozzle

just "punch a hole" through the oil/water interface. Maximum oil uptake rates, with the tested configuration, were about 54 l of oil per hour per nozzle.

Based on these tests it appeared that the air atomization technique would have greatest merit for thick oil slicks where the air jet nozzle could be held within the thick oil.

FULL-SCALE BURNS

Experimental Set-up

The site of the full-scale burn experiments was moved from the NRC facility in Ottawa to a rural area west of Ottawa. The location change was initiated to reduce the likelihood of complaints from local residents if the tests did not result in clean burns and to reduce the overall cost of the testing. The testing was conducted in a 10 metre x 5 metre above ground swimming pool filled with approximately .75 metres of water. The burner was held above the tank using two 50 mm x 75 mm x 5 mm steel box beams. The air jets were mounted on a submerged frame which was suspended from the sides of the burner. Photos 1 and 2 show the general experimental setup. Oil was held under the burner using a square retaining ring (1.4 m x 1.4 m) constructed from 10 cm x 10 cm and 5 cm x 15 cm lumber. Oil was placed inside the ring by pouring it onto a small spill plate floating inside the ring. Ignition was accomplished by simply igniting the oil pool with a propane torch attached to the end of an extension handle. This torch was initially mounted in the throat of the burner chimney and ignited remotely via a standard propane barbecue piezo-electric sparking device but this system proved to be unreliable so it was abandoned after the first test. Air was supplied to the atomization nozzles via a large diesel powered air compressor capable of delivering approximately 1 m³/s at 690 kPa. The air line from the compressor was fed to a manifold connected to five pressure regulators and electronically controlled valves (see Photo 3). From these valves 6 mm diameter air lines were passed underwater to the air nozzles mounted below the burner. The nozzles used were 6 mm diameter brass tubes fitted into the flexible hosing. The cleanliness of the burns was measured by videotaping each test



Photo #1: Burner assembly mounted above tank

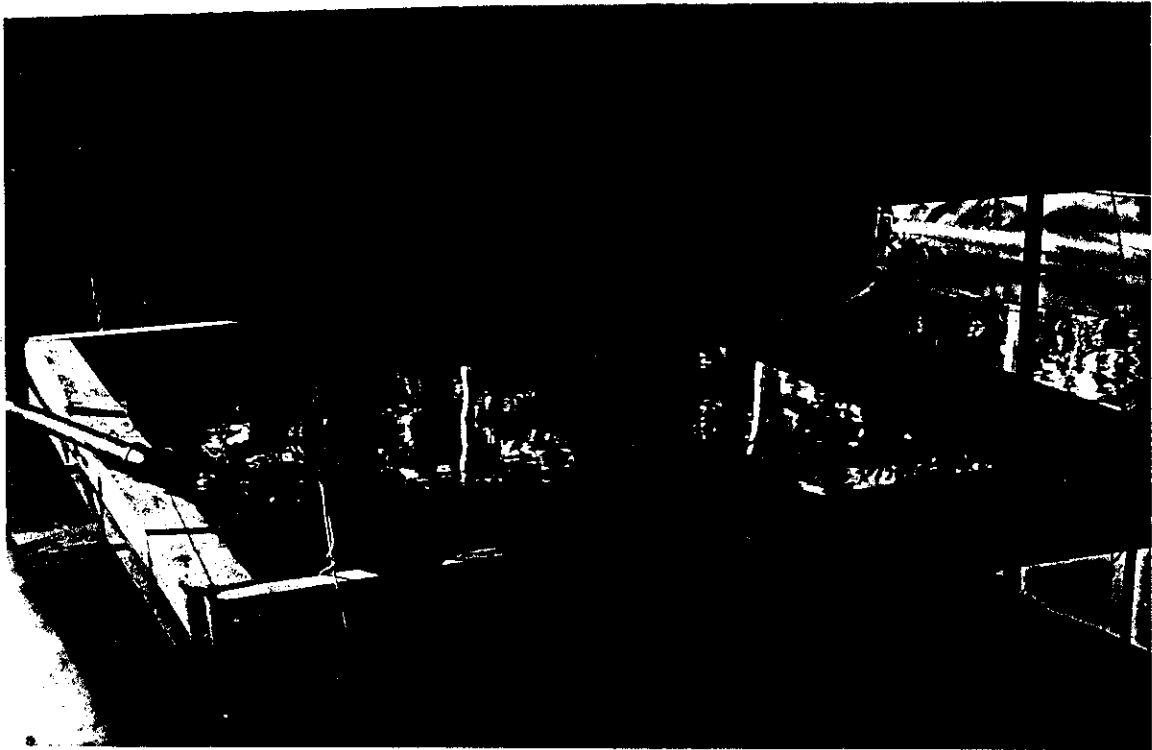


Photo #2: Air Jet array and oil containment zone

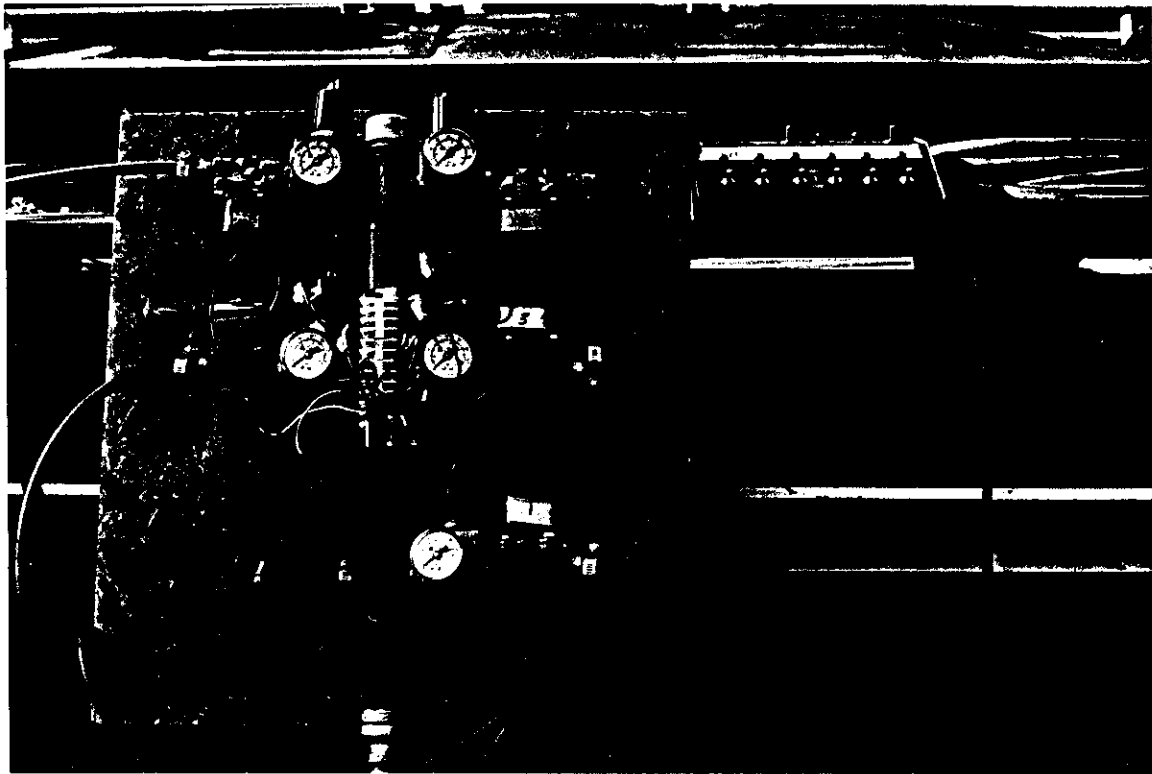


Photo #3: Pressure regulators, electric valves and control box

and by taking light measurements of a standard grey card (18% reflectance) and the smoke plume. The reflectance technique was adapted from Comfort, 1989.

The reflectance of the smoke plume was measured using a hand held light metre and a Gray Card (of 18% reflectance). The luminance of both the plume and the card were measured for each test. The reflectance of the plume was then calculated as follows:

$$\text{Plume Reflectance} = \frac{\text{Grey Card Reflectance (18\%)} \times \text{Plume Luminance}}{\text{Card Luminance}}$$

These data were then related to standard smoke densities by measuring the reflectance of the grey shades from the standard density chart. These data are summarized in Table 2 from Comfort, 1989.

TABLE 2
REFLECTANCE OF SMOKE DENSITY CHART

Density #	<u>Spotmeter Reading</u>		Reflectance
	EV	Luminance (Foot-Lamberts)	
1	10.5	50	68%
2	9.9	40	55%
3	9.5	29	40%
4	8.7	18	24%
5	8.1	11	15%

Experimental Procedure

The general method followed for each test was as follows:

- i) the air pressure was adjusted to the required setting with the nozzles in operation to account for un-equal pressure distribution and pressure drops in the distribution manifold;
- ii) the appropriate quantity of oil was placed in the retaining ring;
- iii) a grey card reflectance light reading was taken;
- iv) the video camera and timer were started;
- v) the air jets were turned on;
- vi) the oil was ignited and time of ignition recorded;
- vii) the reflectance of the resultant smoke plume was measured;
- viii) 35 mm photos of the burn were taken;
- ix) the time of extinction of the burn was recorded; and
- x) the air jets and video camera were turned off.

Test Results

The primary objective of the burning tests was to identify operating parameters which would result in clean burns. Burn rates and burn efficiency (visual only) were also recorded throughout the testing. A total of 27 tests were completed; the test conditions and results are summarized in Table 3; smoke density estimates are summarized in Table 4. A video tape of all tests has been provided to the scientific authority.

TABLE 3
FULL SCALE BURNER TEST RESULTS

Test	Oil Type	Oil Volume (litres)	Thick	No. Nozzles	Height of Nozzle Above Water (mm)	Nozzle Diameter (mm)	Air Pressure kPa	Start Burn	Stop Burn	Length	Comments
1	fresh crude	50	20	5	0	6	varied	1:13	7:55	6:42	chimney didn't function; pool burned out of control
2	fresh crude	5	2	5	0	6	200	2:43	4:03	1:20	started clean; turned dirty
3	fresh crude	5	2	5	0	6	200	0:49	1:45	1:04	clean 1st half then dirty
4	fresh crude	5	2	3	0	6	200	1:15	2:14	:59	dirty burn
5	fresh crude	5	2	5	0	6	200	1:26	2:30	1:04	cleaner than run #4
6	fresh crude	5	2	0	0	--	--	8:30	9:34	1:04	dirty but with flames out top
7	fresh crude	5	2	5	0	6	140	1:15	2:12	:57	camera not on
8	fresh crude	5	2	5	0	6	140	1:48	2:48	1:00	very dirty
9	fresh crude	5	2	5	0	6	275	1:37	2:25	:48	cleaner burn
10	fresh crude	10	4	5	0	6	275	6:55	8:12	1:17	very dirty
11	fresh crude	5	2	5	0	6	600	1:45	2:40	:55	initial white plume then cleaner; no video
12	fresh crude	5	2	5	0	6	600	1:06	1:56	:60	initial white plume then cleaner
13	fresh crude	5	2	5	-10	6	600	1:55	N/A	N/A	incomplete burn, emulsion and dispersion formed
14	burn residue from above	4		5	0	6	600	1:23	N/A	N/A	incomplete burn again
15	fresh crude	5	2	5	0	1 x 8	275	1:21	2:16	:55	still poor burn; nozzles moved to 4 mm above water
16	fresh crude	5	2	5	4	1 x 8	275	1:15	2:30	1:15	cleaner with periods of white smoke
17	fresh crude	5	2	5	4	1 x 8	600	1:29	2:30	:56	very clean orange flame
18	fresh crude	5	2	5	4	1 x 8	415	1:05	1:47	:42	clean with a few puffs of black smoke
19	diesel	5	2	5	4	1 x 8	415	1:15	2:20	1:05	clean orange flame
20	diesel	5	2	5	4	1 x 8	600	1:10	2:10	1:00	very clean
21	diesel	5	2	5	4	1 x 8	275	1:08	2:20	1:12	dirty burn
22	weathered crude	5	2	5	4	1 x 8	275	1:45	3:10	1:25	clean with slight trace of smoke
23	weathered	5	2	5	4	1 x 8	415	1:48	2:55	1:07	very clean
24	weathered	5	2	5	4	1 x 8	600	1:58	2:53	:55	same as 60 psi test
25	weathered	10	4	5	4	1 x 8	600	1:50	3:20	1:30	clean burn
26	weathered	15	6	5	4	1 x 8	600	2:40	4:40	2:05	clean burn
27	weathered	15	6	5	4	1 x 8	600	2:25	4:00	1:35	clean burn; chimney glowed red

TABLE 4
SMOKE DENSITY ESTIMATES BY LIGHT METER READINGS

Test	18% Reflectance Spotmeter	Grey Card Luminance	Spotmeter	Plume Luminance	Plume Reflectance %	Smoke Density	Smoke Observations
1	Not Taken						
2	Not Taken						
3	20	1067	20	1067	18	5	initially clean then very dirty
4	19.5	754	19.25-20	634-1067	15-25	4-5	very dirty
5	19.33	670	20	1067	29	4	cleaner than run #4
6	17.66	211	19	533	46	2-3	dirty with flames out top
7	20.33	1341	18.33-19	335-533	4.5-7	5	very dirty
8	19.33	670	16.33-19	84-533	2-14	5	very dirty
9	18.5	377	19-19.5	533-754	25-36	3-4	cleaner burn
10	Not Taken						very dirty
11	18.33		19-20	533-1067	29-57	2-4	initial white smoke then cleaner
12	19	533	20	1067	36	3	initial white smoke then cleaner
13	Not Taken						
14	Not Taken						
15	Not Taken						
16	17	133	17.5-18.5	189-377	25-51	2-4	clean with periods of white smoke
17	17.33	168	19	533	57	2	very clean: orange flame
18	16.5	94	17.5-18.3	189-328	36-63	1-3	clean with few puffs of black smoke
19	14.66	26	18	267	180	1	clean orange flame
20	14.33	21	17	133	114	1	very clean
21	14.33	21	14-15.5	16.7-47	14-40	3-5	dirty burn
22	17.5	189	19	533	51	2	clean with slight trace of smoke
23	17.6	211	19.5	754	64	1	very clean burn
24	18	267	19.33	670	45	3-4	very clean: same as 23
25	18	287	19	533	36	3	very clean
26	18	267	19	533	436	3	very clean
27	18	267	19	533	436	3	very clean: chimney glowed red

• by manufacturers calibrations luminance = 266.7×2 (Spotmeter Value - 18)

In the first test the bottom of the chimney was located approximately 0.3 metres (1 ft.) from the water's surface and 50 litres of oil were placed in the containment zone (this resulted in a slick thickness of 2.5 cm). The oil was ignited with the propane torch mounted inside the throat of the chimney but the fire rapidly spread to the entire pool. The chimney did not function properly in this orientation and the fire simply burned out the downwind side of the burner platform. The extensive heat generated by this burn eventually resulted in the melting of a portion of the pool liner to the waterline and more significantly in the failure of the downwind steel support. This steel beam became pliable with the heating and bent under the weight of the burner resulting in the downwind side of the burner dropping approximately .15 metres (6 inches) as seen in Photo 4. This beam was replaced and the chimney base lowered to within 0.15 metres (6 inches) of the water surface for the remaining burns. In this configuration the chimney operated properly and funnelled all flames up the chimney. For the remaining tests a smaller oil volume was also used to reduce the risk of support failure.

Tests 2 through 6 were carried out to determine the effect of the number of nozzles on burn cleanliness. Oil thickness (2 mm), type (fresh crude) and nozzle operating pressure (200 kPa) were kept constant. Reducing the number of nozzles operating (from 5 to 3 to zero) resulted in a progressively dirtier burn. The burn duration and quantity of burn residue were essentially identical for all of these tests regardless of the air jet nozzles.

Tests 7 to 9 investigated the effect of nozzle pressure on the burn cleanliness by operating at 140 and 275 kPa and keeping all other parameters constant. It was evident from these burns that the higher pressure resulted in cleaner burns. In test 10 the oil volume was doubled and the jet pressure set to 275 kPa. The burn was essentially the same as test 9 with the exception of a slightly longer burn time as would be expected. The oil depth did not appear to affect the cleanliness of the burn.



Photo #4: Test facility after first burn

In tests 11 and 12 the jet pressure was increased to the maximum possible (550–620 kPa depending on nozzle) with the compressor being used. The resulting burn was essentially smoke free.

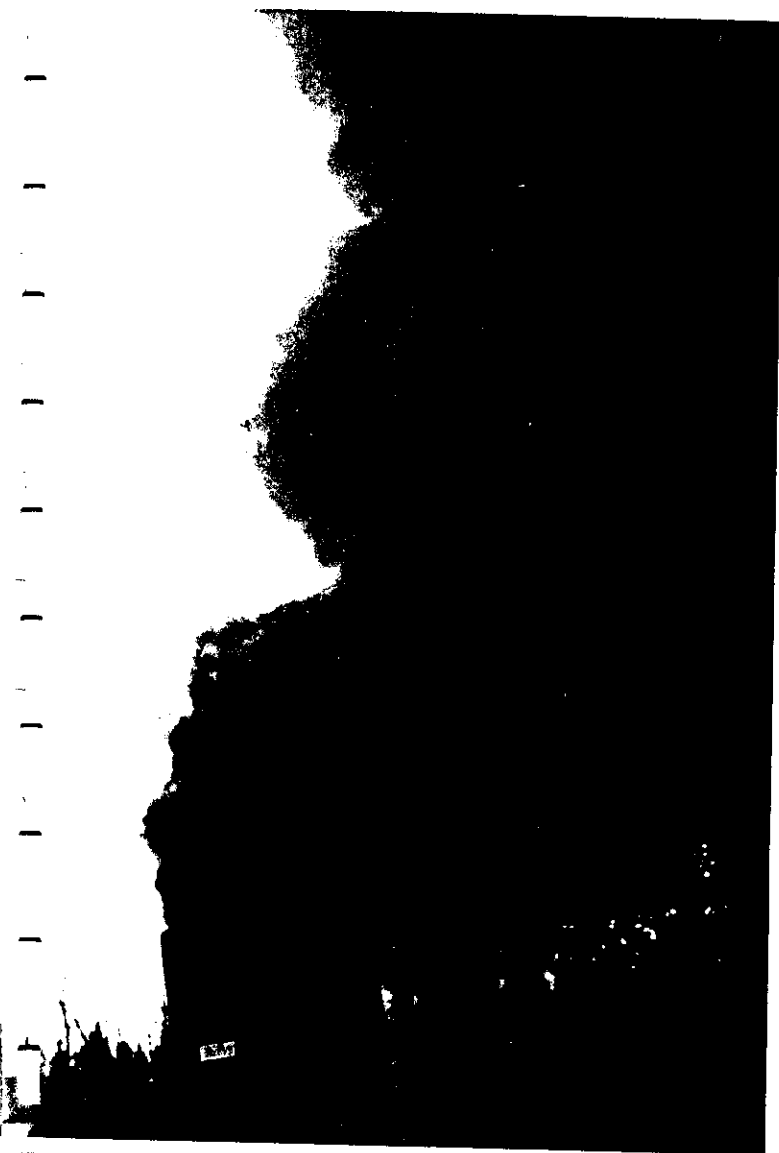
For test 13 the nozzles were submerged to a position about 1 cm below the water/oil interface and the jets operated at the maximum pressure. This resulted in a very dirty burn and the formation of a water-in-oil emulsion which did not burn fully. Considerable product remained after the fire extinguished.

The nozzles were then moved back to the water surface and four litres of fresh crude were added to the burn residue. Again the burn was not efficient (test 14) and left considerable residue. This residue was then removed, the nozzles pinched to increase the jet velocity at a given pressure and fresh oil added. Test 15 again was inefficient so the nozzles were moved up slightly above the water surface (4 mm) for test 16 which burned much cleaner. The primary observation to be made from tests 13 through 15 is that it is very critical that the air jet nozzles be mounted slightly above the water surface to eliminate excessive water uptake and oil emulsification.

Tests 16, 17 and 18 investigated the burn efficiency of the modified jets (brass tubes were pinched to a 1 mm wide by 8 mm long slot and mounted slightly above the water surface) with variation in air supply pressure. This increased the average air velocity at the orifice by a factor of 3.3. At 275 kPa the burn was generally clean with periodic puffs of dark smoke (see Photos 5 and 6). At 600 kPa the burn was very clean with light orange flames emanating from the chimney (see Photo 7). At 415 kPa the burn was clean but the flames were a darker orange in colour indicating a cooler burn (see Photo 8).

Tests 19 to 21 were a repeat of the operating conditions of tests 16 to 18 with diesel fuel. The results were essentially identical to the fresh crude oil tests (see Photos 9–11).

Tests 22 to 24 used Ontario light crude oil weathered by bubbling air through a diffuser, placed in the bottom of a 1/3 full barrel, at 270 kPa for 4 hours. The viscosity of the weathered oil was 27 cp compared to 23 cp for the fresh crude. Again the burns behaved very similar to the fresh crude and diesel with the exception



Photos #5 & 6: Run #16 Ontario light crude oil: 275 kPa nozzle pressure

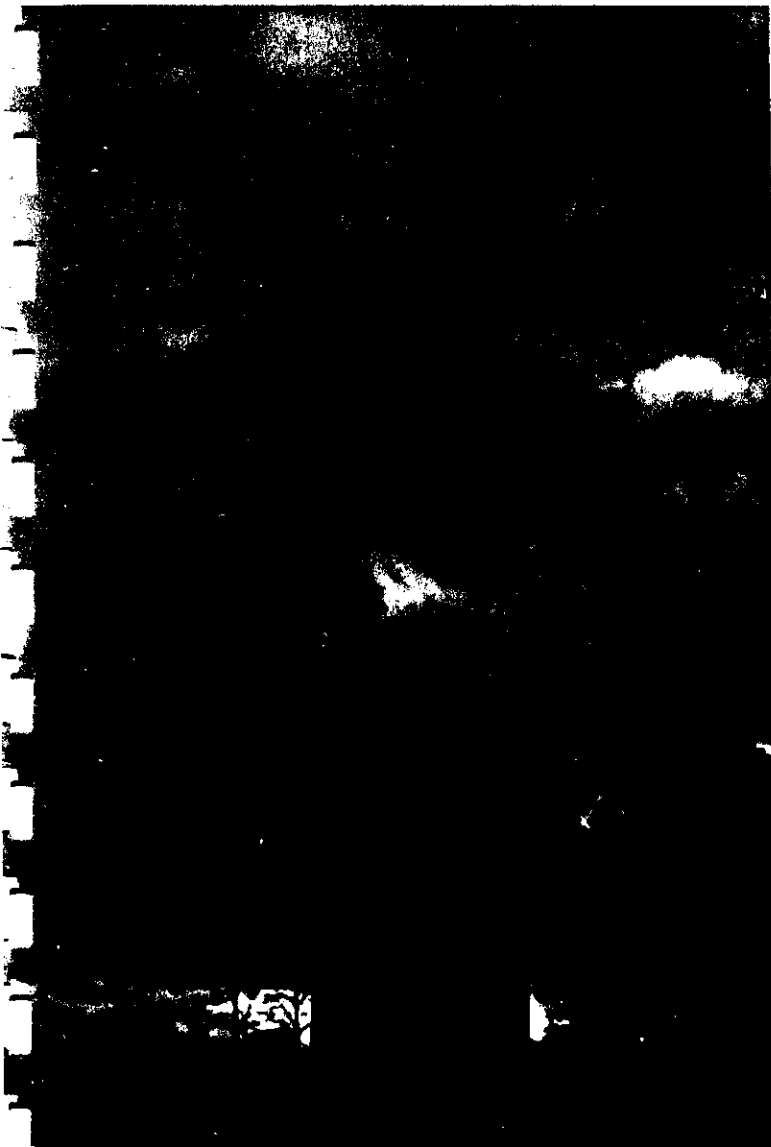
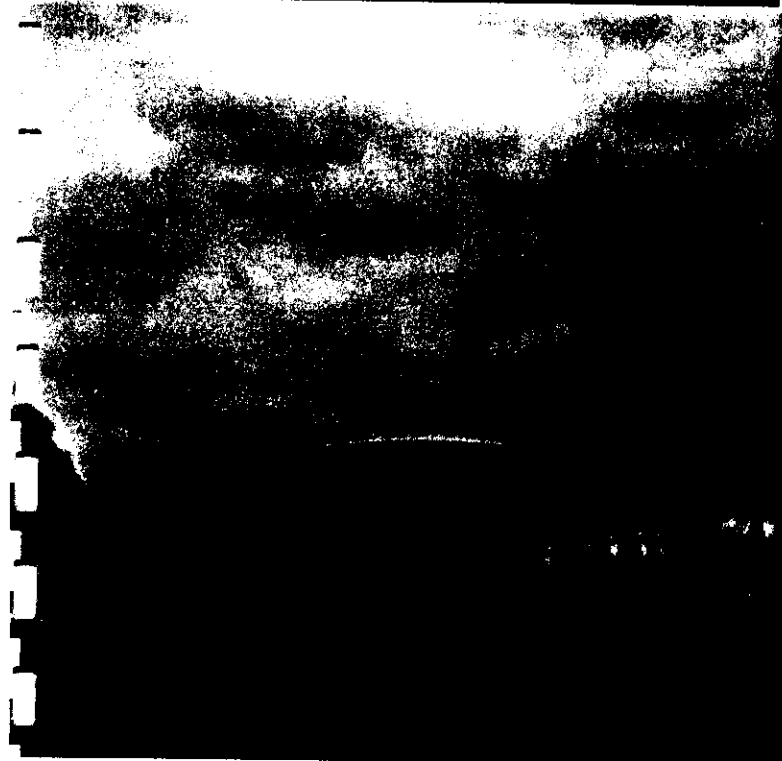
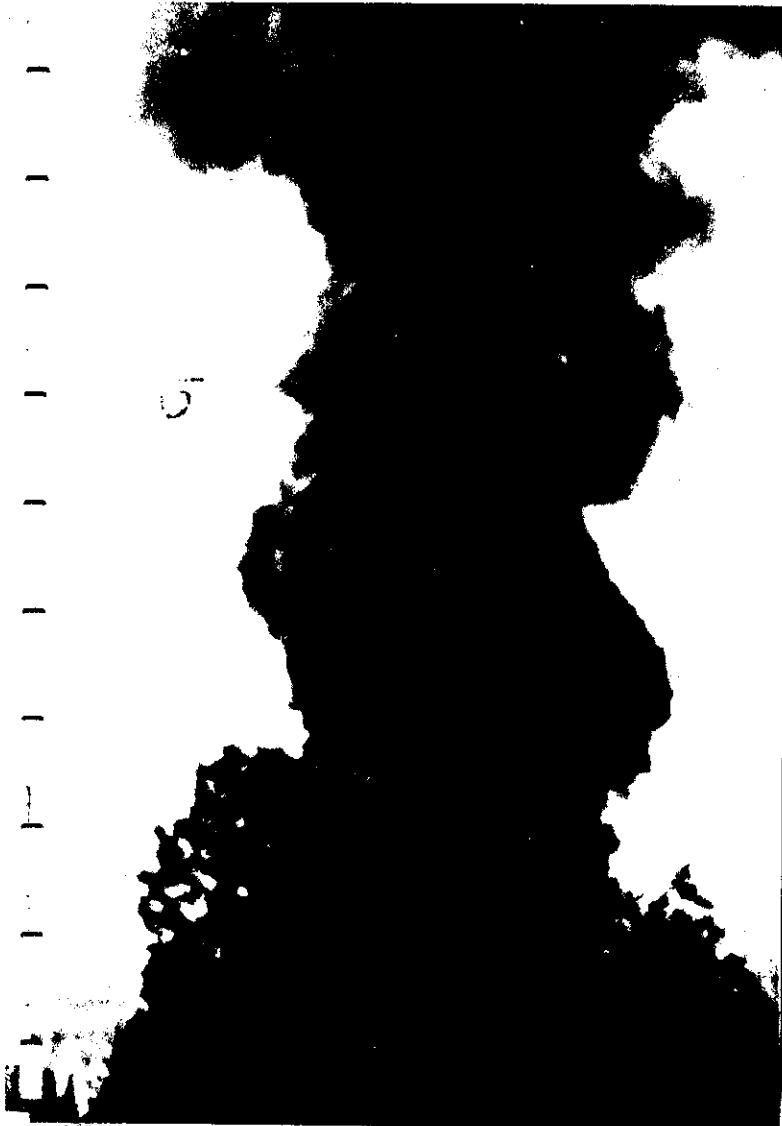


Photo #7: Run #17 Ontario light
crude: 600 kPa nozzle pressure



Photo #8: Run #18 Ontario light
crude: 415 kPa nozzle pressure



(clockwise from top left)

Photo 9: Run #21 Diesel fuel:
275 kPa nozzle pressure

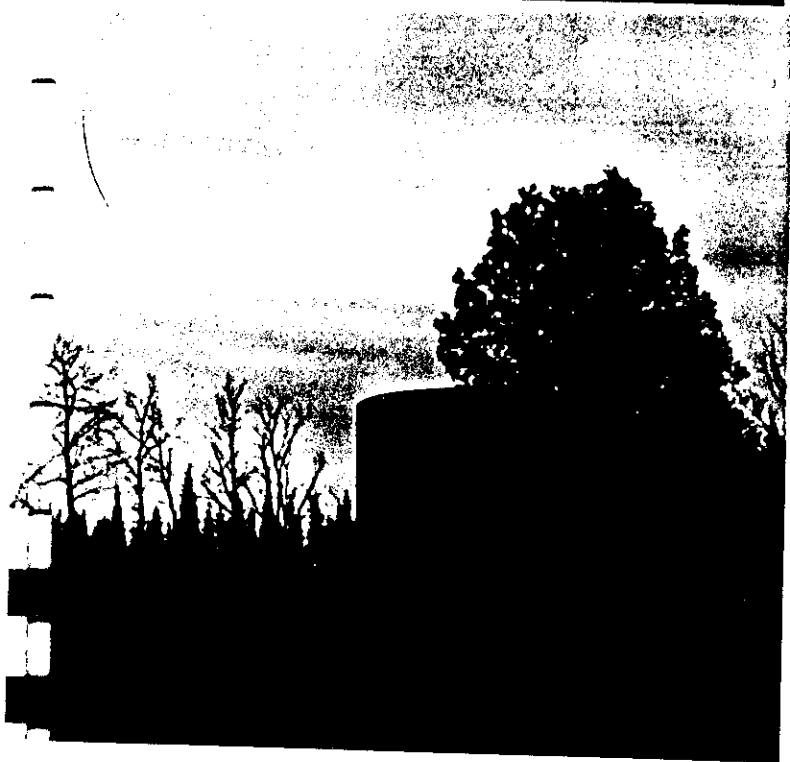
Photo 10: Run #19 Diesel fuel:
415 kPa nozzle pressure

Photo 11: Run #20 Diesel fuel:
600 kPa nozzle pressure

that the 415 kPa burn was generally as clean and hot as the 600 kPa test (see Photos 12-14).

The final three tests (25-27) investigated the effect of oil thickness on the burn efficiency. The burns were conducted at maximum pressure for 2 and 3 times the oil thickness of the previous tests. Burn cleanliness and efficiency were not affected by the oil thickness. In the final burn (test #27) the burner chimney glowed red indicating the hottest burn of all the tests which were conducted (see Photos 15 and 16).

The results of the spotmeter readings of the grey card and smoke plume indicate that the method has some merit for estimating smoke plume density. In general, lower smoke densities were recorded by this method for those runs where the burn was observed to be cleaner. Unfortunately, the method also estimated smoke densities of up to level 3 for very clean "smokeless" burns; see tests 24 to 27.



(clockwise from top left)

Photo 12: Run #22 Weathered crude:
275 kPa nozzle pressure

Photo 13: Run #23 Weathered crude:
415 kPa nozzle pressure

Photo 14: Run #24 Weathered crude:
600 kPa nozzle pressure

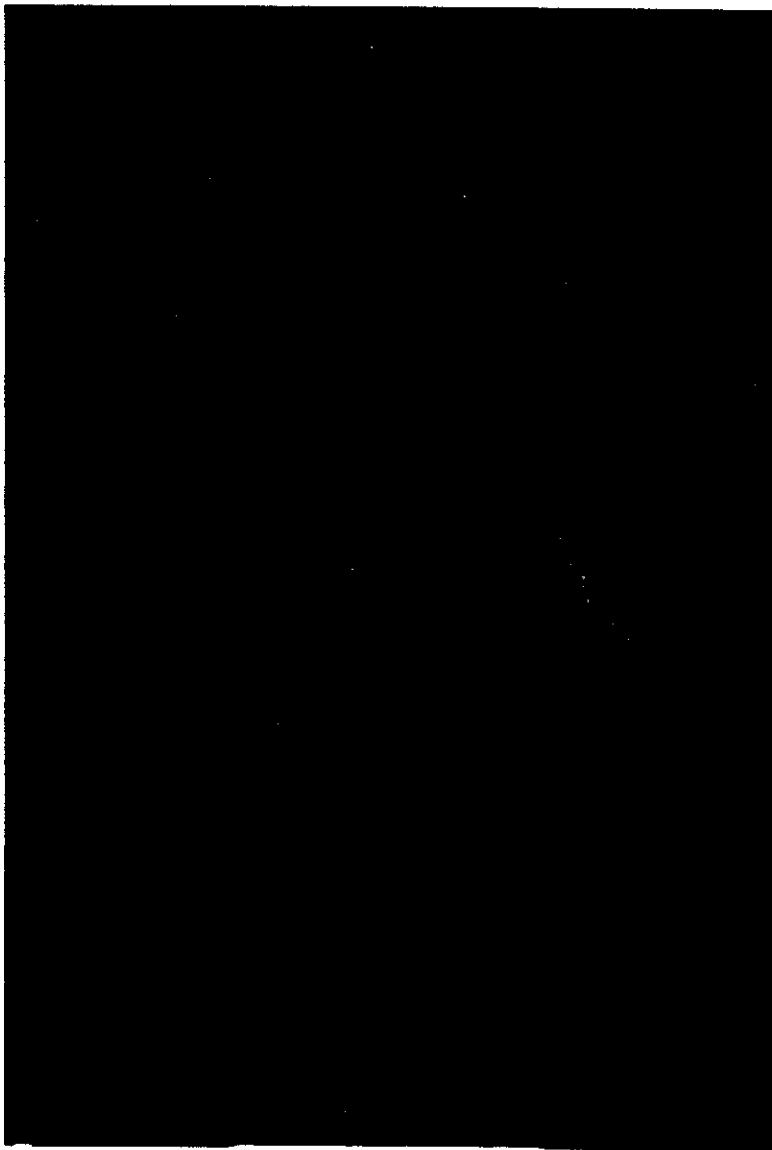


Photo #15: Run #26 Weathered crude
600 kPa nozzle pressure: 3x oil
thickness

Photo #16: Run #27 Weathered crude
600 kPa nozzle pressure: 3x oil
thickness

CONCLUSIONS

- i) Submerged air jets resulted in high water:oil ratios in the small scale testing and poor burns in the large scale testing.
- ii) Nozzle shape appeared to have little effect on oil atomization rates in the small scale testing.
- iii) Larger diameter nozzles and lower pressures increased the oil atomization rates in the small scale testing. These conditions also reduced the burn cleanliness in the large scale tests. This may suggest that higher oil volumes were being supplied to the burner under these conditions thus resulting in an incomplete combustion. However, this theory is not supported by the burn durations which were essentially identical for all tests with similar initial oil volumes.
- iv) The burner did not function properly when positioned 0.6 metres above the water. In this position the chimney was not able to draw in enough air to direct the flames and smoke through the burner.
- v) Clean burns were achieved using the large scale burner when it was placed within .15 metres of the water surface, all 5 air jets were operated at supply pressures of 415 kPa or greater, and the nozzles were placed at or slightly above the water's surface.
- vi) Only a small quantity of burn residue was left at the end of each burn (approximately 50 mLs) with the exception of the test with the submerged air jets. When the jets were submerged, a dirty, incomplete burn resulted along with the formation of a water-in-oil emulsion.
- vii) The oil pool immediately under the burner ignited and burned during the testing. Fire can spread to areas outside the influence of the burner if oil thicknesses in its vicinity exceed about 1 mm. This would cause severe safety problems and result in unclean burning around the burner. If the oil in the vicinity of the burner is less than 1 mm very little oil would be removed by the burner.
- viii) The burner could be placed at the apex of a fireproof boom for clean burning of collected oil at a burn rate of 5 L/min.

REFERENCES

Comfort, G. 1989. Tests to Evaluate the Effect of a Waterjet Barrier on the Burning Efficiency of a Floating Oil Slick. Environment Canada Report EE-112.